Part I : 50 Years of Antenna R&D

Antoine G. Roederer ,
Scientific Advisor - Delft University of Technology
Past Head of Electromagnetics and Space Environment Division, European Space Agency

Part II : Promising Space Antenna Concepts and Technologies

Cyril Mangenot
Head of Electromagnetics and Space Environment Division
European Space Agency

Abstract :- The first part is an update of an invited "Retirement from ESA" presentation and covers the review of 50 years of Antenna R&D from 1964 to 2014, 35 of which with the European Space Agency. .
Some highlights, including Log-periodics, Lindenblad-type broadcast antennas, reflect arrays for radar, and a variety of active, semi-active array and reflector multi-beam antennas for space are reviewed, with emphasis on R&D and innovation. This first part focuses on some new concepts that were successfully demonstrated, developed in industry and used for real projects. Conclusions include some possible lessons learned and trends.

In the second part, key space antenna challenges for future Satellite Antenna R&D are proposed and discussed. These aim at deploying larger antenna apertures, increasing telecommunication satellite throughput, enhancing antenna coverage and polarization reconfiguration. New antenna concepts and technologies are also needed for innovative Earth Observation and

Science instruments ranging from P and L-band radars to Space borne millimeter wave and Terahertz sensing instruments. The need for new approaches for satellite/antenna modeling and testing is also discussed.

Keywords: Frequency Independent Antenna, Broadcast Antenna, Radar Antenna, Reflectarray Antenna, Satellite Payload, Satellite Antenna, Antenna Modeling, Multi-beam Array Antenna, Conformal Array Antenna, Multi-beam Reflector Antenna, Antenna Beam-forming, Semi-Active Antenna, Multi-matrix Antenna, Deployable Reflector Antenna, Shaped Reflector Antenna, Contoured Beam Antenna, Remote Sensing Antennas, Synthetic Aperture Radar, Satellite Antenna Testing

Part I
50 Years of Antenna R&D:
Highlights and Some Lessons Learned

Antoine G. Roederer

Scientific Advisor - Delft University of Technology

Past Head of Electromagnetics and Space Environment Division
European Space Agency
ESTEC – Noordwijk – The Netherlands

Part I - Overview

I. Foreword

II. Some simple R&D from the sixties

III. R&D in space antenna engineering
  - Radiating elements
  - Multibeam antennas
  - Reflector Technology
  - Reflectarrays
  - Other technologies

III. Some messages

IV. Acknowledgments

I. Foreword

- This is an update of an invited “Retirement from ESA” presentation made at the 30th ESA Antenna Workshop, in ESTEC, Noordwijk in May 2008
- It covers the period from 1964 – 2014 in five Institutions:

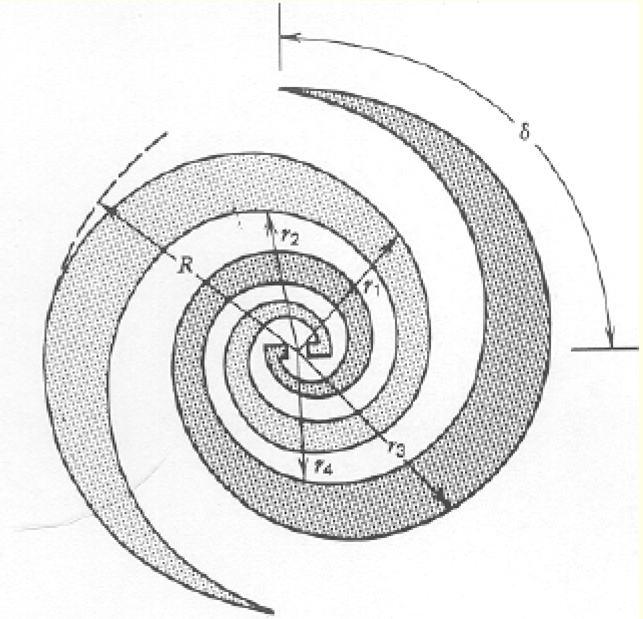
1. University of California, Berkeley (1964-1966)
2. Jampro Antenna Company, Sacramento (1967)
3. Thomson CSF Radar – Bagneux France (1968-1972)
4. European Space Agency- Noordwijk – The Netherlands (1973-2008)
5. Delft University of Technology - The Netherlands (2009-present)

Some simple R&D from the sixties

Frequency Independent Antennas @ Berkeley

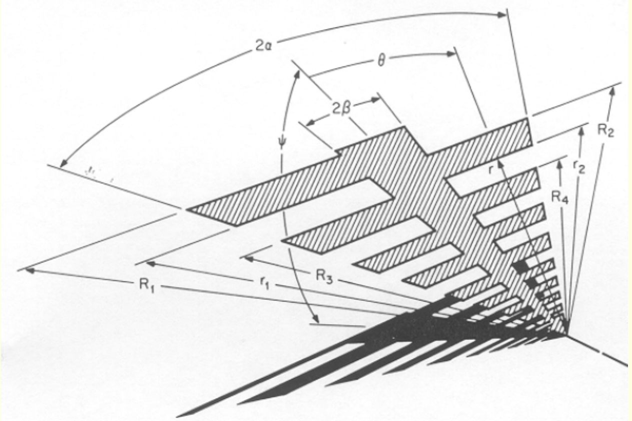
- Frequency independent antennas:

  - Rumsey[*] & Duhamel 1957
  - Quasi blue sky academic research
- Shape invariant to scale → independent of frequency.
- Supported by the US Army



Stutzman, W. and G. Thiele, Antenna Theory and Design, Wiley, New York, 1981, p. 284.

- Log-periodics: a class of quasi frequency independent antennas
- Band-widths can be 10:1 or greater.

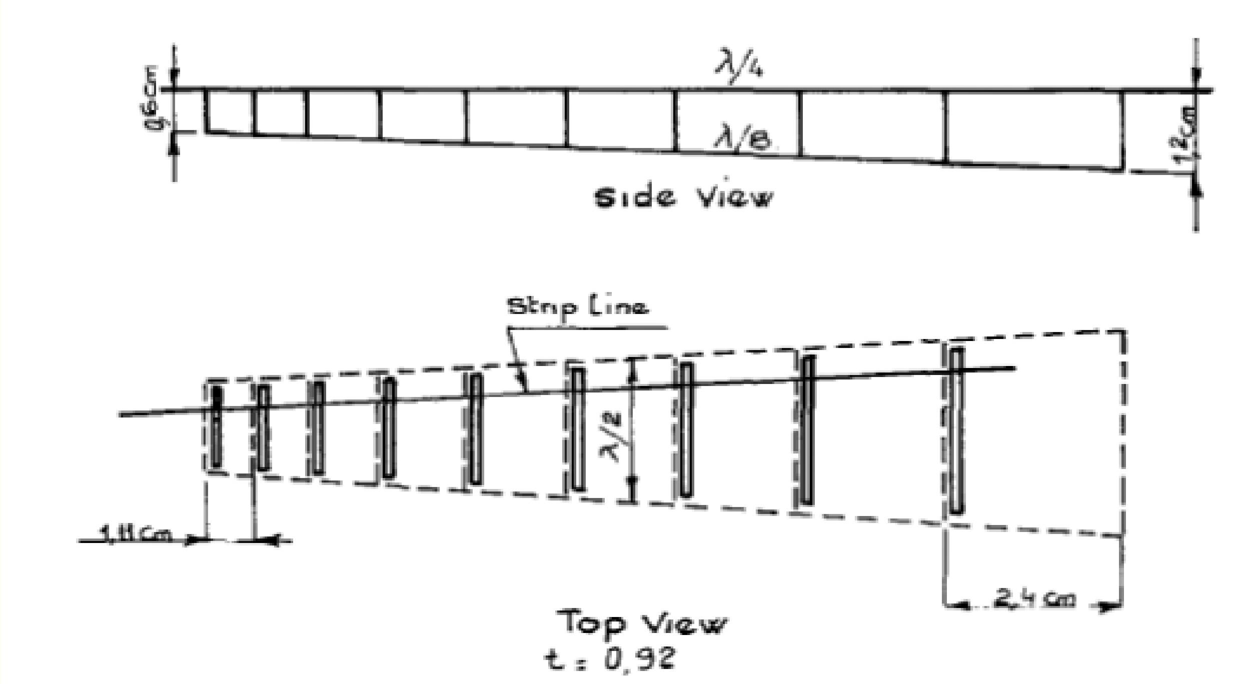


---

[*] Rumsey, V.H., “Frequency Independent Antennas,” 1957 IRE National Convention Record, Pt. 1, March 1957, pp. 114-118

Strip-line fed log-periodic slot array

- **In 1965, LP dipole arrays demonstrated**
- **Low profile LP array of EM coupled cavity backed slots then investigated and built at UC Berkeley***

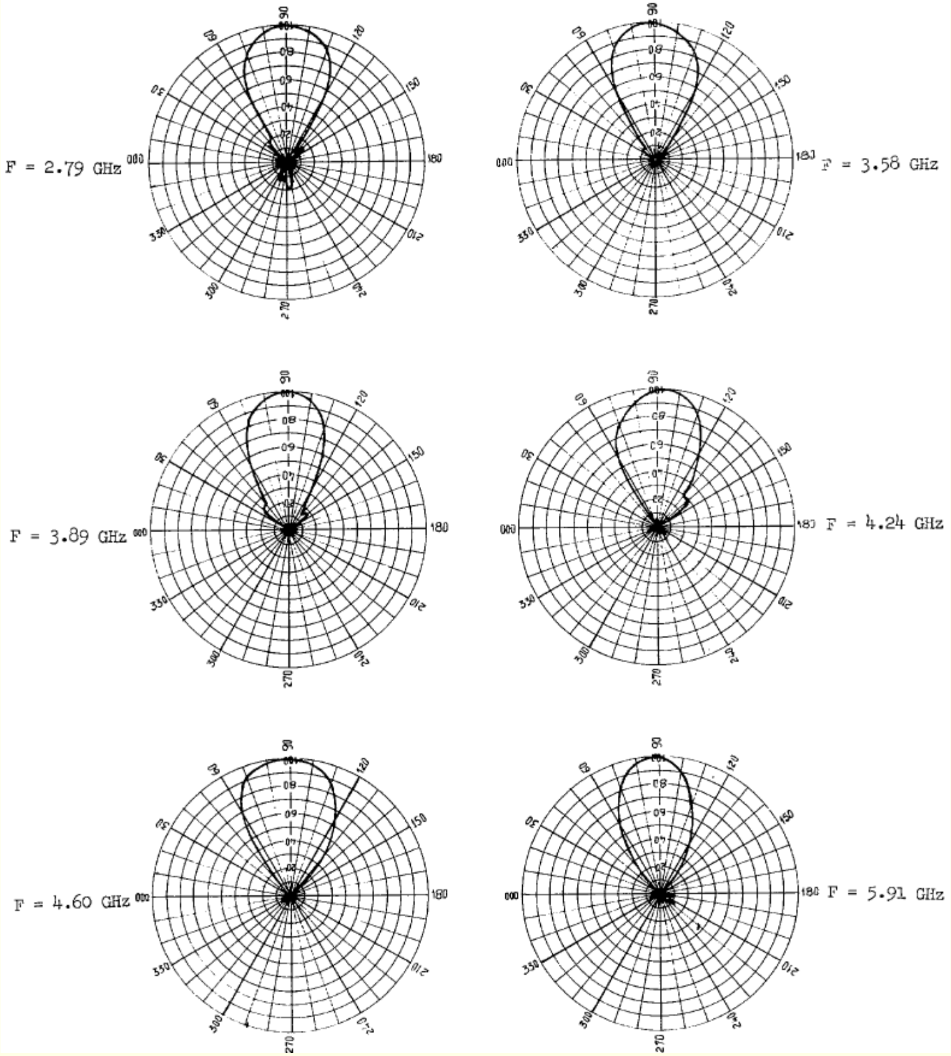

λ/4
0,6cm
λ/8
1,2cm
Side View
Strip Line
λ/2
1,11cm
2,4 cm
Top View
t = 0,92

***Roederer, A., "A log-periodic cavity-backed slot array,"**
***Antennas and Propagation, IEEE Transactions on*, vol.16, no.6, pp. 756-758, Nov 1968**

Strip-line fed log-periodic slot array

Measured patterns from

2.79 GHz to 5.91 GHz



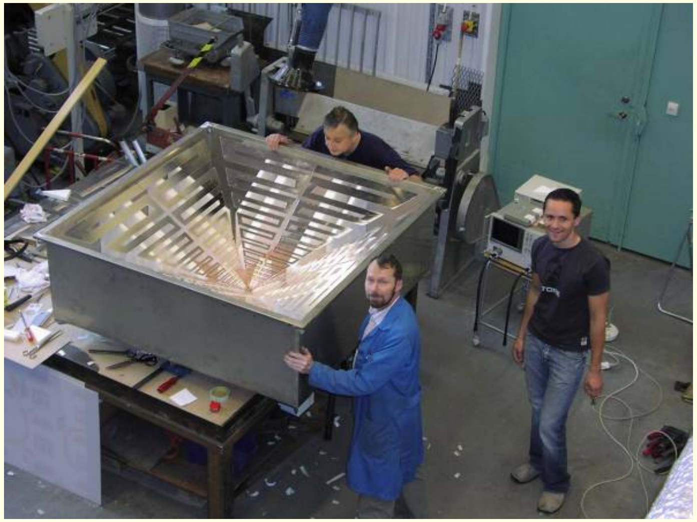
→ Good Frequency Independent performance

Frequency Independent Antennas: Evolution

- 1950-1960 University blue sky research
- 1960-1970 US Army funded R&D
- 1970 - …: Massively used by defence
- 1970 - ….: Limited for civil use: EMC testing, GPR?

Major users should pay the R&D (here defence not ESA)

**New (spin-in) work on-going for Radio astronomy[*]
UWB…**

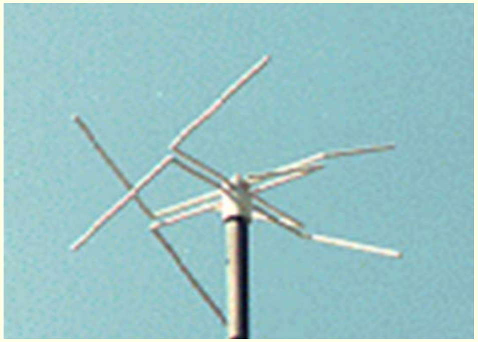


The “Eleven” LPD antenna Feed
(Courtesy P.S. Kildal C.U.T)

[*] Olsson, R., Kildal, P.S., Weinreb, S.,
“The Eleven Antenna: A Compact Low-Profile Decade Bandwidth Dual Polarized Feed for Reflector Antennas”, *AP, IEEE Trans.*, vol. 54, no.2, pp. 368-375

FM Broadcast Antenna 1967-2014

- **January 1967: US introduced CP for FM**
- **February 1967: JAMPRO (1 engineer) needs antenna in 3 months**
- **March 1967: Study to compact complex 4 dipole Lindenblad**



Lindenblad antenna (1940!):

- 4 (folded) dipoles on λ/3 circle tilted 30° & fed in phase

- Why CP ? Good question for student orals

FM Boadcast Antenna 1967-2014

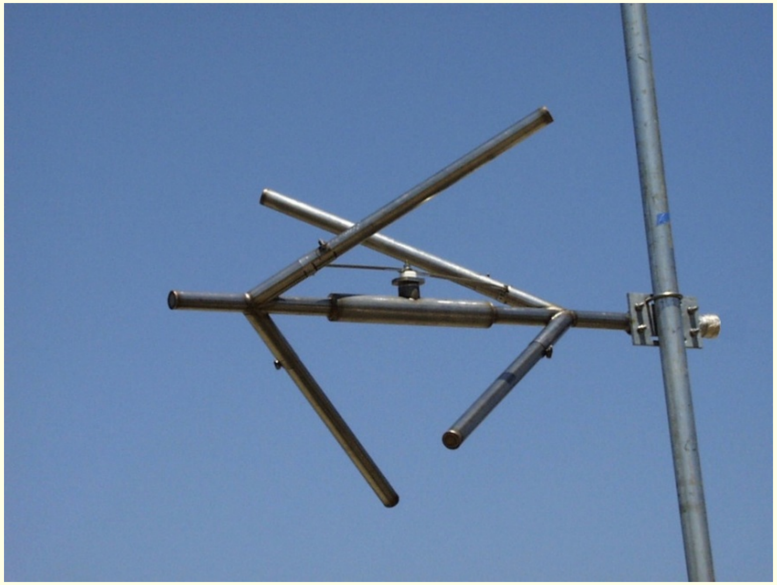
April 1967 proposed design:

- Two facing V's @ ≈ λ/3 inclined 30°
- Two arm excitation from single coaxial feed inside support.
- Narrow band but easily tuneable
- Why Circular Polarization?

$$E_v = I \times \left(\sin\frac{\pi}{6}\right) \times \left(e^{+j\frac{\pi}{6}} + e^{-j\frac{\pi}{6}}\right) = I\sqrt{\frac{3}{2}}$$

$$E_h = I \times \left(\cos\frac{\pi}{6}\right) \times \left(e^{+j\frac{\pi}{6}} - e^{-j\frac{\pi}{6}}\right) = j \times I\sqrt{\frac{3}{2}}$$

- Equal vertical and horizontal fields with 90^0 phase shift → CP
- Less complex than Lindenblad



JAMPRO's Circularly polarised FM broadcast antenna "Penetrator"

(Courtesy JAMPRO)

1970: Patented by JAMPRO

*More details in Jasik Antenna Engineering Handbook

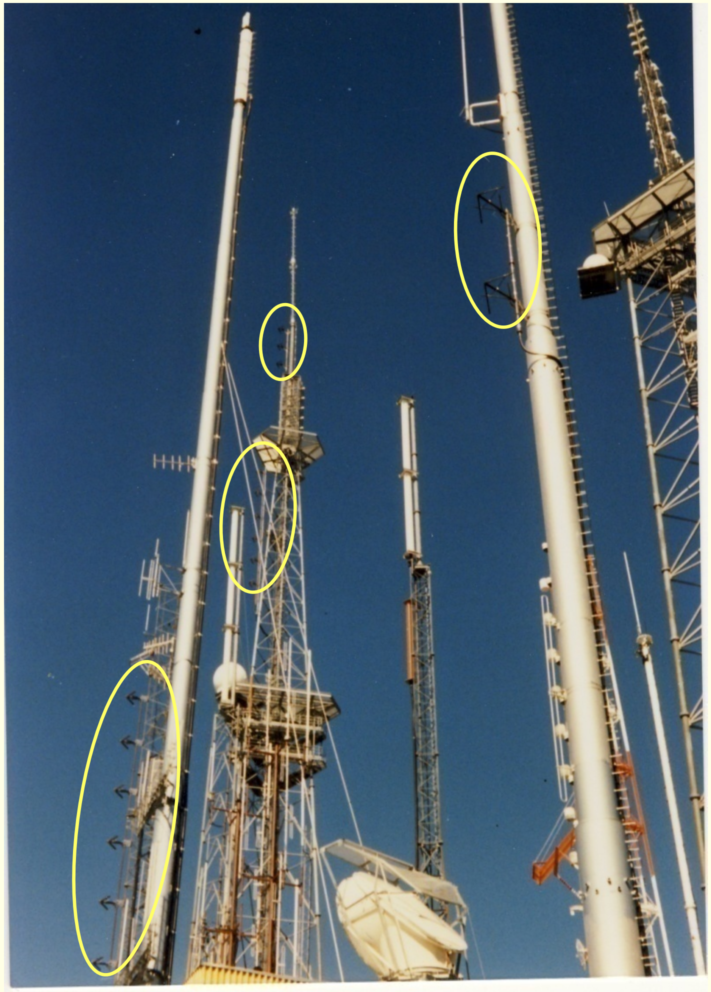
FM Boadcast Antenna 1968-2008: Messages

- **2014: Over 4000 in operation***

Messages

- **Fast targeted innovation can pay-off**
- **No new technology involved: only innovative design**

*** Source: www.JAMPRO.com**



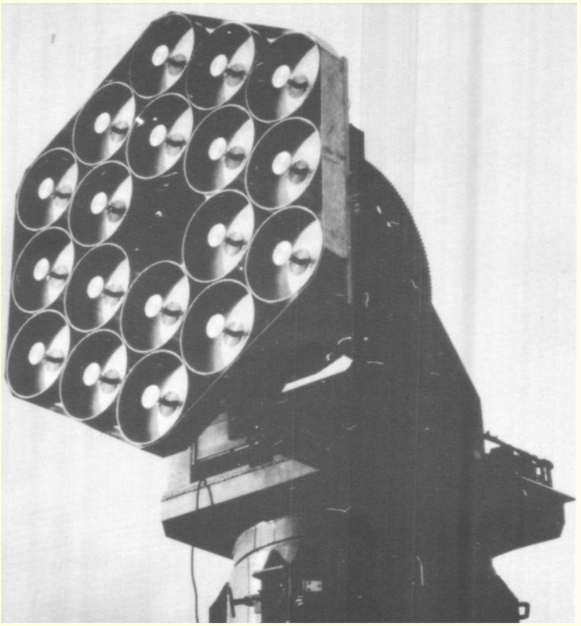
Four arrays of JAMPRO “Penetrators” visible at Mt Wilson above Los Angeles

II. R&D in space antenna engineering

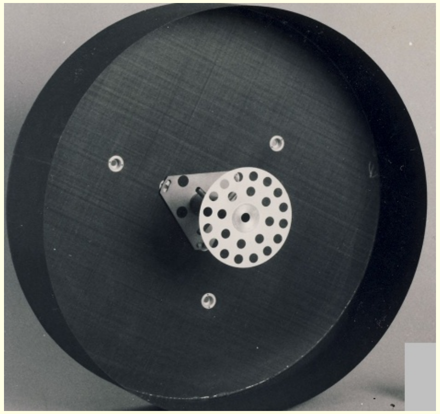
Radiating elements (1973-2008)

1974 : ESA R&D on active L-band multi-beam arrays. (Array, diplexers, amplifiers, beamformers)

Optimisation, design & development of radiating elements at Ericsson (now Ruag-Space)

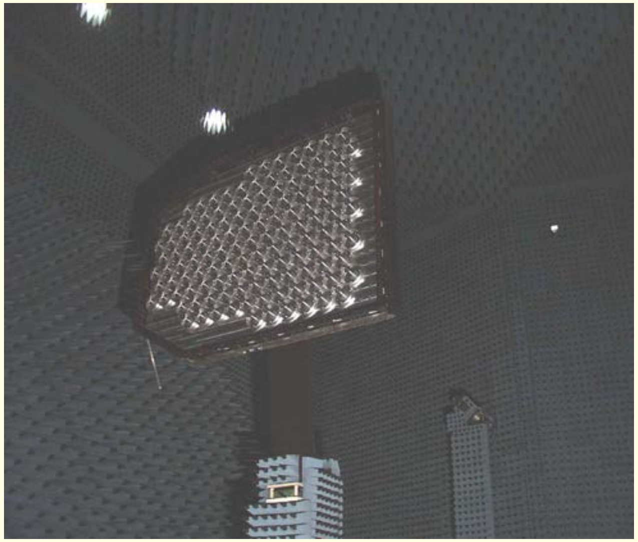


1975 ESA – LM Ericsson Multibeam Array Model



Andersson, A.; Bengtsson, P.; Molker, A.; Roederer, A., "Short backfire antenna arrays for space communications", *AP-S Int. Symp. 1977* pp. 194-197, Jun 1977

Radiating elements
30 years later & beyond



Saab-Space* Export L-Band feed array (128 elements)
in the world standard DTU-ESA Test Facility

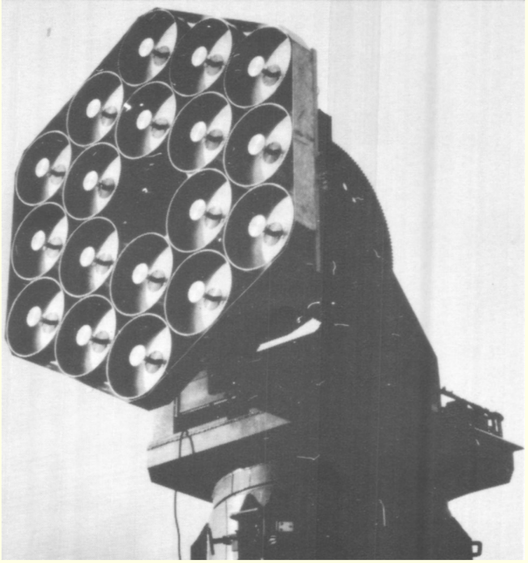
2004 ICO Arrays
Saab Ericsson Space*/ Boeing

- **Thousands exported to US, more on order**
- **Active multibeam arrays did not take off**
- **Many feed arrays** derived **from ESA R&D**

*** Now Ruag-Space**

Radiating elements: Messages

1975



ESA – LM Ericsson*
Multibeam Array R&D Model

2005

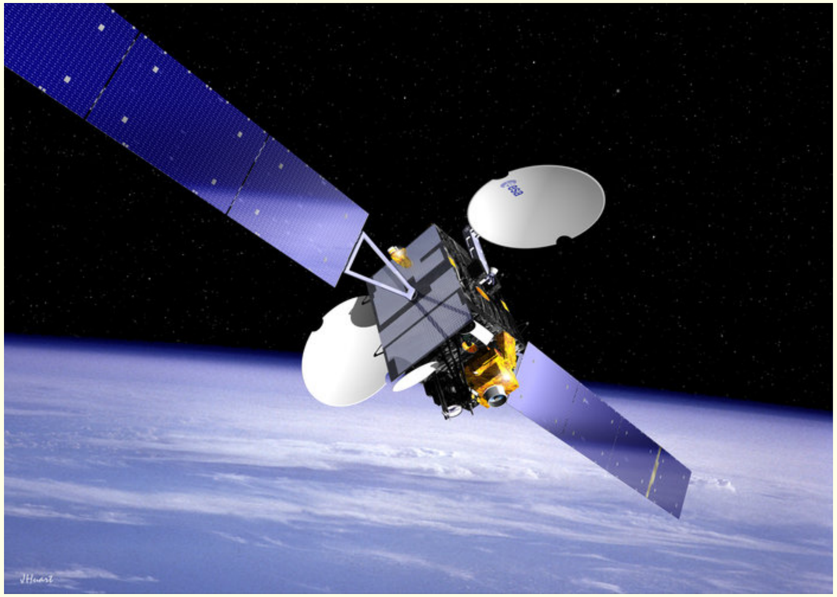
Thousands of LM Ericsson* ICO
Array Elements exported to US

- **ESA well targeted seed antenna R&D @ L-band paid off**
- **Same for C-Band @ ASTRIUM Munich & for Ka-Band at Alenia…**
- **ESA // R&D for new reference antenna test techniques & facility @ DTU: big success (Tests for Thuraya, ICO, SMOS…)**

* Now Ruag-Space

Semi-Active Multi-beam Antennas

1988: Key requirements for Artemis Mobile Payload L-Band Front-end:



ESA Artemis Satellite

Courtesy ESA- J.Huart

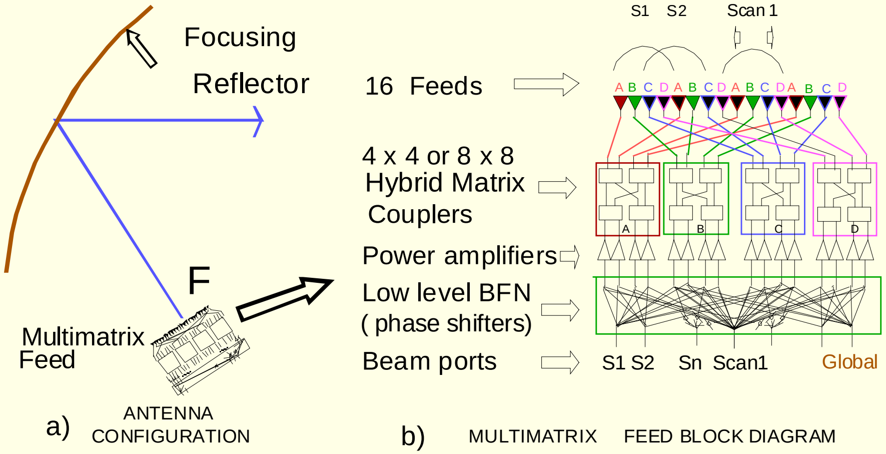
- Multiple overlapping beams
- Traffic to beam flexibility
- Power efficient Tx front-end

A 4 to 5 m (possibly inflatable) reflector was then assumed

Semi-Active Multi-beam Antennas

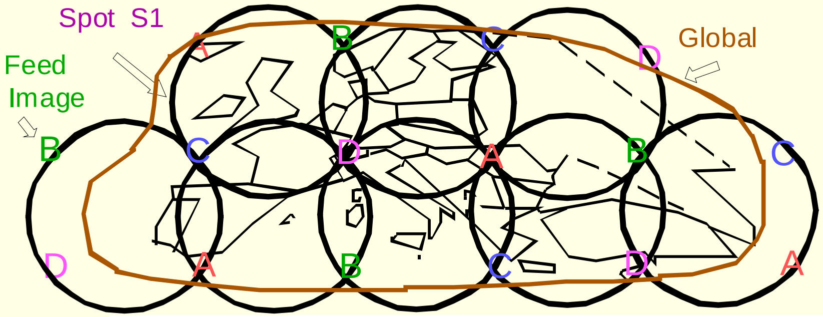
The semi-active multi-beam antenna concept was proposed*:

- Butler-like matrices between power amplifiers & feeds
- Phase control at amplifier inputs to redistribute the power in focal plane
- → full beam/trafic reconfigurability
- All amplifiers at nominal level & best η
- Only requires available technologies


Focusing
Reflector
F
Multimatrix
Feed
S1 S2 Scan 1
16 Feeds
A B C D A B C D A B C D A B C D
4 x 4 or 8 x 8
Hybrid Matrix
Couplers
A
B
C
D
Power amplifiers
Low level BFN
(phase shifters)
Beam ports
S1 S2 Sn Scan1 Global

a) ANTENNA CONFIGURATION

b) MULTIMATRIX FEED BLOCK DIAGRAM


Spot S1
Feed
Image
Global
A
B
C
D
B
C
D
A
B
C
D
A
B
C
D
A

Semi-active multi-matrix feed concept*

---

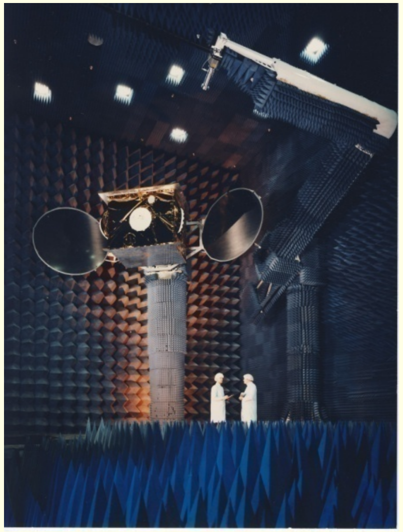
*Roederer A., “Feeding device for a multiple beam antenna”, EU Patent EP0420739, 1991 (appl.1989)

Semi-Active Multi-beam Antennas

Semi-active reflector antennas & derivatives used for:

- 1996-1998 IMARSAT III F1,F2,F3,F4,F5 →
- 2001 ESA ARTEMIS LLM Payload
- 2005 …. Various Mobile COMSATS
- Under study for future missions:

  EUTELSAT S-band mobile TV….



INMARSAT III with semi-active front-end
Courtesy Airbus Defence & Space

Concept successfully extended to arrays*:

- Demonstrated with ESA patented 3x3 hybrids
- Demonstrated with Thales Alenia Space F patent for conical shaped data transmission antenna

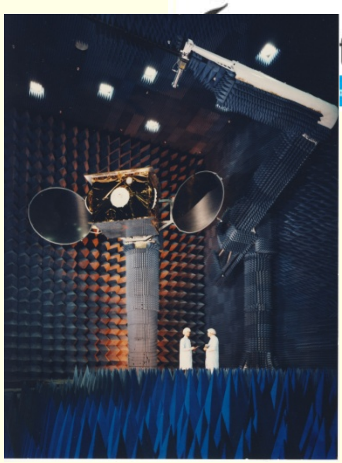
Semi-active conformal array
(Thales Alenia Space F – ESA)

---

*Roederer A., van't Klooster K., EU Patent EP0497652, 1993

Semi-Active Multi-beam Antennas & derivatives

Targeted innovation at close to zero cost can have large impact. Big market…



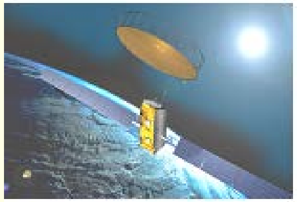
Inmarsat III

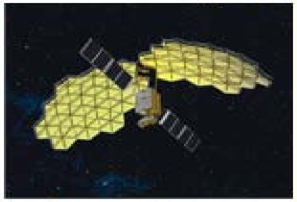
Courtesy Airbus Defence & Space

Garuda

Thuraya

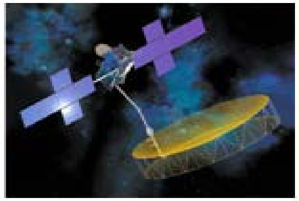
Inmarsat IV





ETS VIII

ICO-G



TerreStar

MSV

Inmarsat XL

Reflector antenna analysis, synthesis, shaping

Thanks to ESA R&D, EU ahead in reflector analysis & shaping

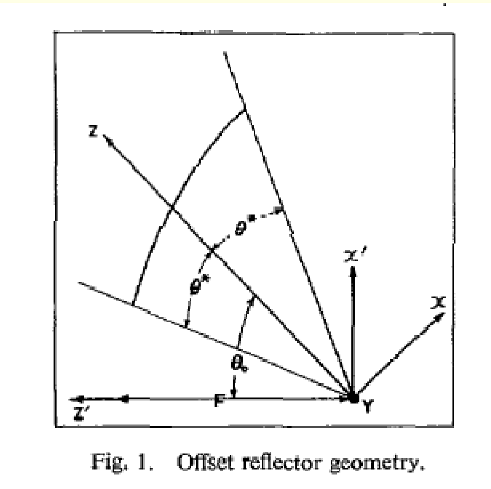
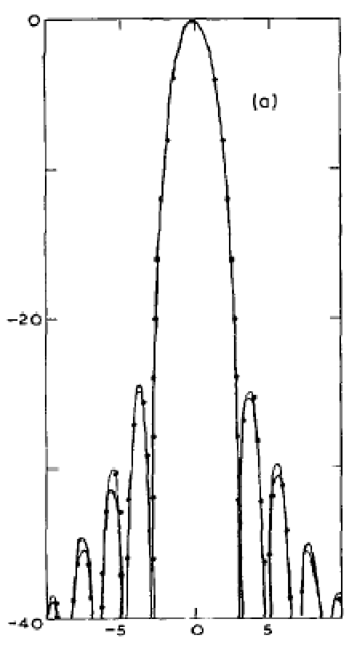
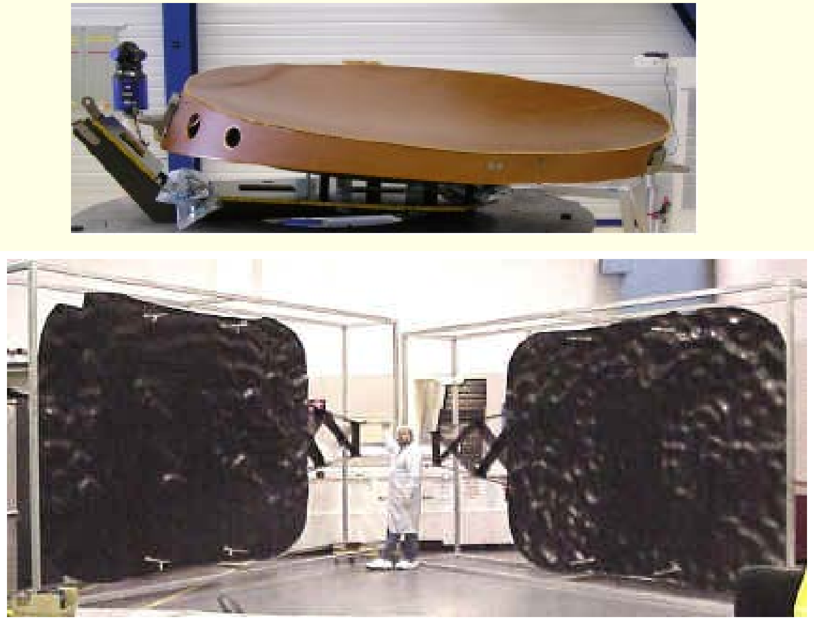


Fig. 1. Offset reflector geometry.



1974 Alan Rudge (computed vs measured)

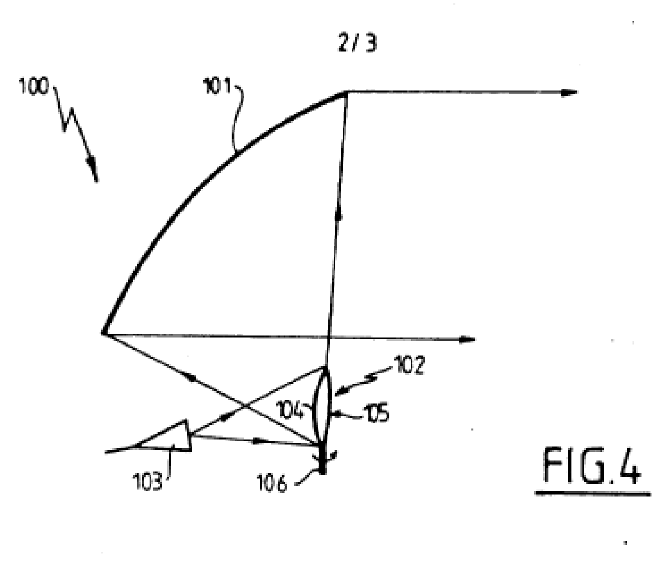


2004 Shaped reflectors (Astrium*)
Gridded (top) & INTELSAT

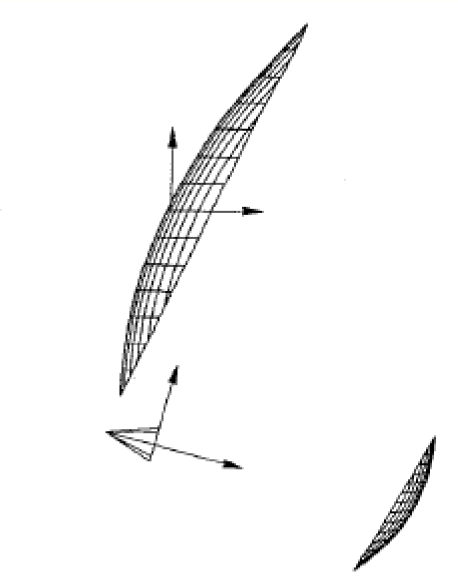
Westcott B. S., Stevens F.A., and Brickell F., "GO synthesis of offset dual reflectors"
***IEE Proc. Part. H*, Vol. 128, No. 1, 11-18, 1981**

*** Now Airbus Defence and Space**

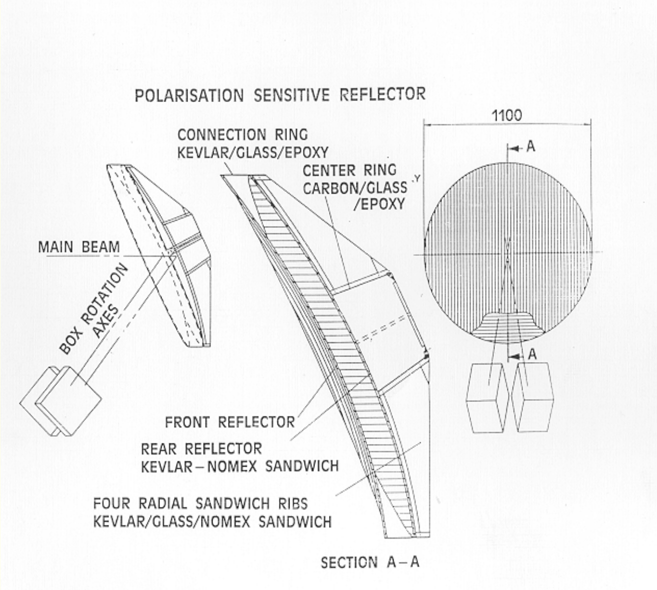
Some internal ESA work on reconfigurable[1,2], shaped and gridded[3] reflectors


2/3
100
101
102
104
105
103
106
FIG.4

Antenna with switchable shaped beam[1]
(click-rotate multifacet shaped subreflector)



Antenna with shapable subreflector[2]


POLARISATION SENSITIVE REFLECTOR
CONNECTION RING
KEVLAR/GLASS/EPOXY
CENTER RING
CARBON/GLASS
/EPOXY
1100
A
Y
MAIN BEAM
BOX ROTATION AXES
A
FRONT REFLECTOR
REAR REFLECTOR
KEVLAR – NOMEX SANDWICH
FOUR RADIAL SANDWICH RIBS
KEVLAR/GLASS/NOMEX SANDWICH
SECTION A – A

Gridded reflectors with identical shells rotated around bore-sight[3]

[1] Roederer A., Crone G., Mica G., "Antenne à faisceau commutable", *Patent* FR8907772, 1989

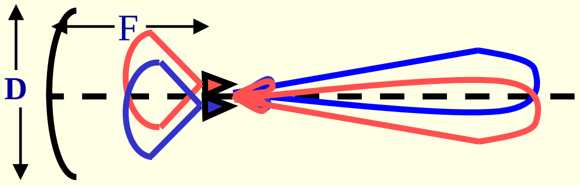
[2] Viskum H.H., Pontoppidan K., Clarricoats P., and Crone G., "Coverage Flexibility by Means of a Reconformable Subreflector", IEEE AP-S Int.Symp., 1997

[3] Roederer A., Crone G., " Double grid reflector antenna", *Patent* US4647936, 1987

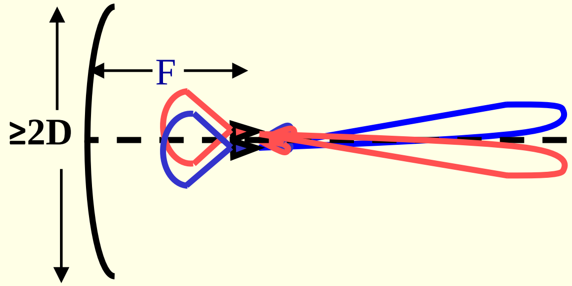
Some internal ESA work on Oversized Shaped Reflectors

Objective: Get closely spaced (ΔΘ) multiple beams with low sidelobes and one feed per beam

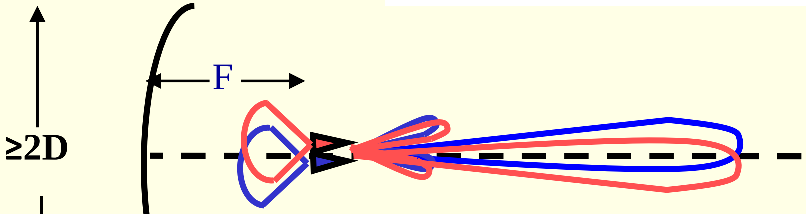
Principle:



“Small” parabola D & F - feeds spacing d
Beam spacing ΔΘ≈d/F radians – High spill over & sidelobes



“Oversized” parabola ≥2D, same F and feed spacing d
Beam spacing ΔΘ≈d/F radians – Low spill over & sidelobes
Narrower beams & low gain at beam cross-over



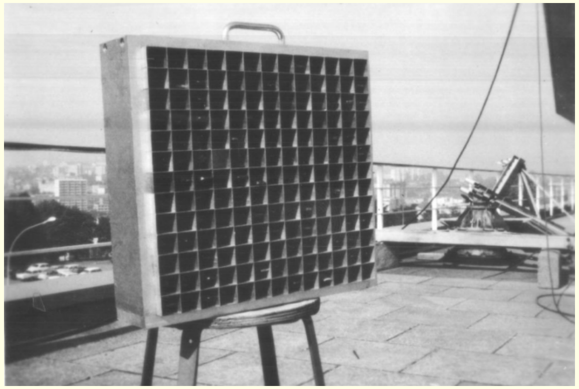
Oversized[1] “optimally shaped[2]” reflector ≥2D, same F and “custom” feeds with same spacing d
Beam spacing ΔΘ≈d/F radians – Low spill over & sidelobes
Broader beams & higher gain at beam cross-over

[1] Stirland S.J., Fox G.P.D., Cols J.-L. “Trends in Multibeam Antennas for Space”, *Millennium Conference on Antennas and Propagation, AP 2000, Davos 2000*

[2] Balling P., Mangenot C. and Roederer A. “Multibeam antenna”, *Patent US2007195000, 2007*

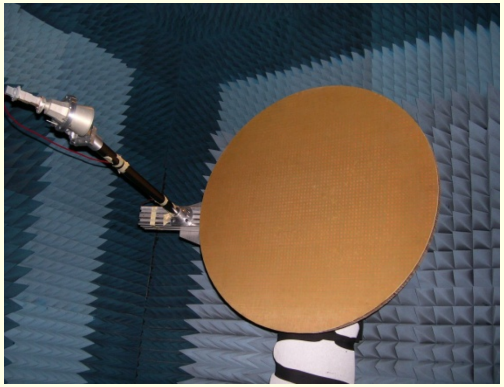
Reflectarrays

1968: with φshifters for radar w. narrow instantaneous band



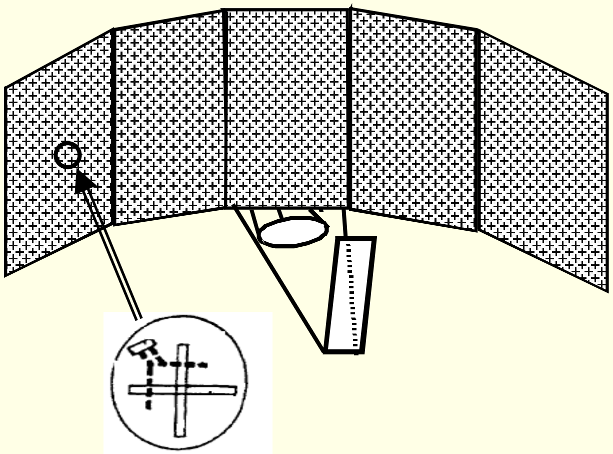
Reflectarray used in the 60's to validate finite array modelling[1]
Courtesy Thomson RDS

Very nice passive multilayer design By Encinar et al.[2]



Multilayer Reflectarray
(Poly. U. of Madrid & Thales Alenia Space – F for ESA)

Design in flat panels[3] multiplies bandwidth & could be OK for SAR



Reflectarray in flat panels approximating a parabola and with polarization rotation and phase-shift

[1] Roederer A.G.,"Etudes des Réseaux Finis de Guides d' Ondes à Parois Epaisses" *Onde Electrique*, Nov.1971

[2] Encinar, J., Zornoza, A., " Broad Band Contoured Beam Reflectarrays For Satellite Antenna", 25th ESA Antenna Workshop, 2002

[3] Roederer A., "Reflector comprising a plurality of panels", *Patent* US2001020914, 2001

Reflector antennas: some messages

ESA targeted R&D on reflector antennas & feeds have been very successful

It has given Europe the lead in reflector analysis & shaping techniques as well as in feed architectures & technologies

EADS astrium

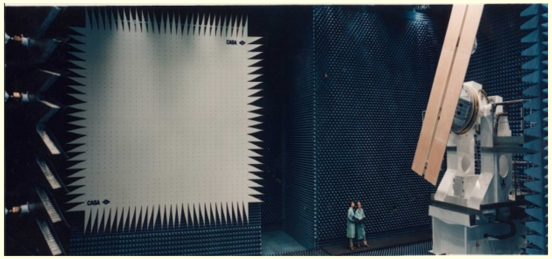
EADS astrium

EADS astrium

Courtesy EADS-Astrium*

***Now Airbus Defence & Space**

Some other “Flown” Technologies from ESA R&D

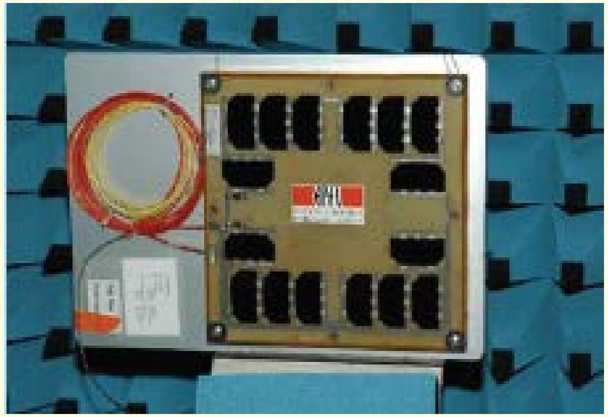


Compensated CATR (TICRA-CASA*)

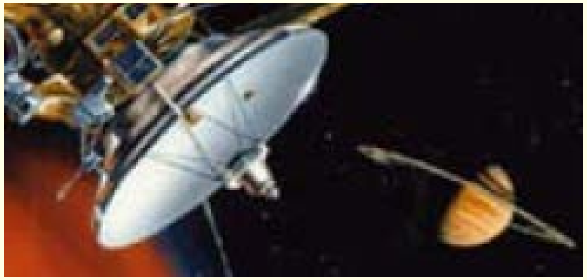
Flying on Giove-A
TAS-I

CASA*
EADS astrium

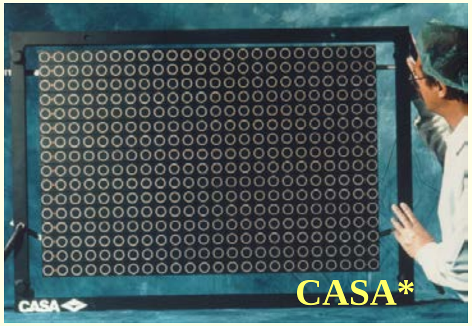
Galileosat Antennas



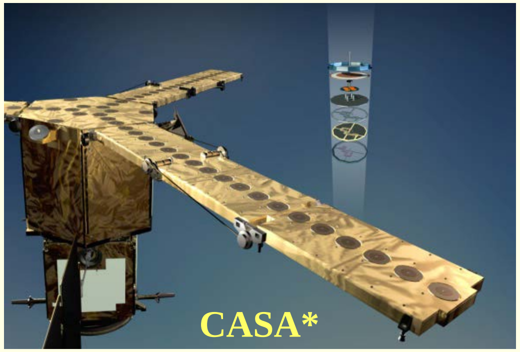
Asolant Solar Cell-Antenna EPFL et al.
↑ 2005



Cassini antenna (TAS-I)



ASAR antenna panel



Aperture synthesis: SMOS

esa
EADS astrium

Herschel 3.5 m “Antenna”

Reconfigurable
Antenna TAS-I

* Now Airbus Defence and Space

Some Messages (1)

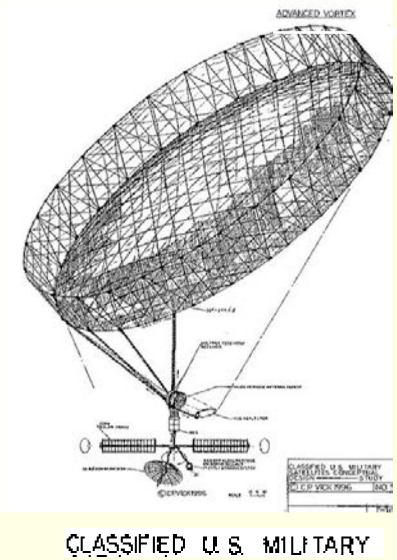
Best is for prime user to pay for
Blue sky or “fashionable” R&D

Spin-in can come later for others

→

Idem for very expensive R&D

→


ADVANCED VORTEX
CLASSIFIED U.S. MILITARY

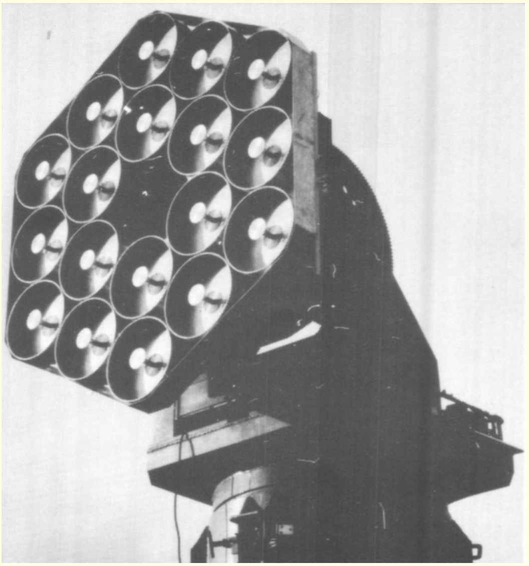
Well targeted R&D to
meet specific
application/needs seems
most effective

→

Courtesy EADS-Astrium (Now Airbus Defence & Space)

Some Messages (2)

1975



ESA – LM Ericsson*
Multibeam Array R&D Model

Keys to active (transmit) arrays:

- Linear Power amplifier efficiency (>30%?)
- Efficient architectures (sub-arrays, sparse?)
- Efficient Beam forming
- Structures/materials/thermal control…..

* Now Ruag-Space

Some Messages (3)

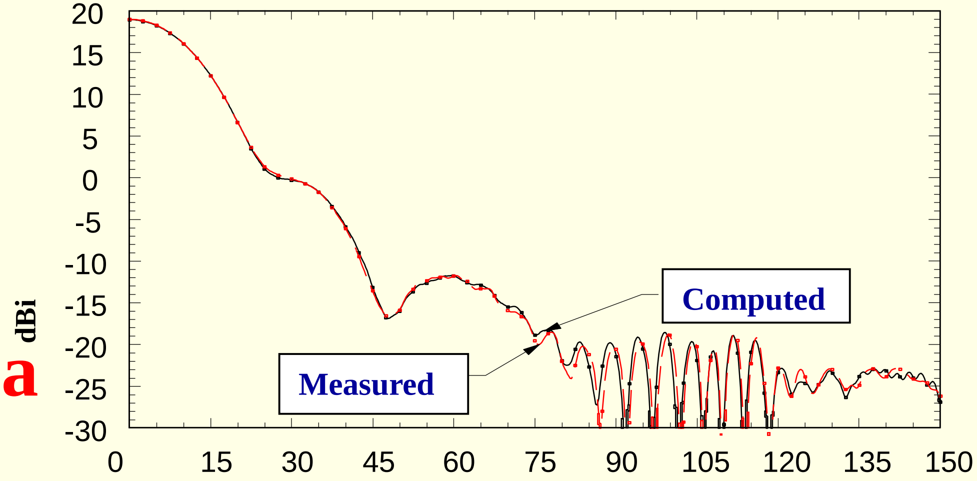
Modelling & Measurement techniques

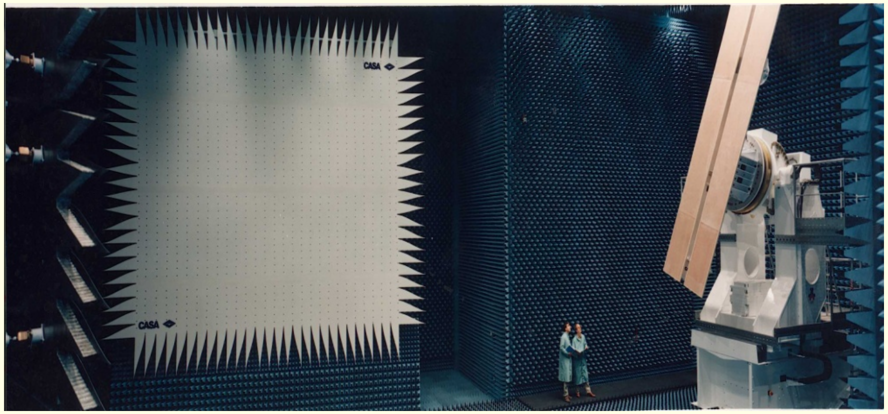
Collaborative R&D between:

Users+Industry+Academia

is vital

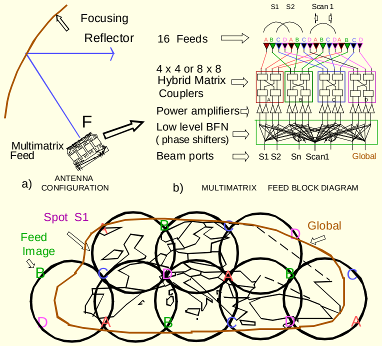
for complex antenna systems

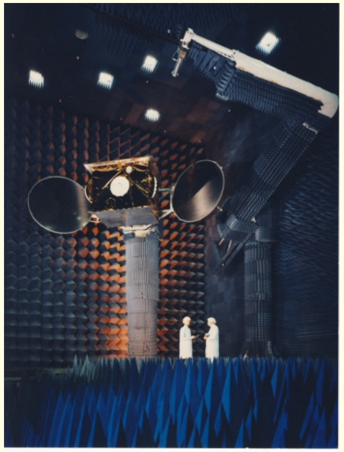




Some bottom lines?

1. Also teach Signal processing + Solid state + Materials …to Antenna Engineers
2. More Targeted Multidisciplinary R&D & Concurrent Engineering
3. Organise & stimulate innovation: systematically present & discuss together problems to resolve in companies, workshops & networks


Focusing
Reflector
F
Multimatrix
Feed
a) ANTENNA CONFIGURATION
S1 S2 Scan 1
16 Feeds
A B C D A B C D A B C D A B C D
4 x 4 or 8 x 8
Hybrid Matrix
Couplers
A B C D
Power amplifiers
Low level BFN
(phase shifters)
Beam ports
S1 S2 Sn Scan1 Global
b) MULTIMATRIX FEED BLOCK DIAGRAM
Spot S1
Feed
Image
Global
A B C D
B C D A B C
D A B C D A



Thanks to my teachers, to ESA, TU Delft & to Colleagues for 50 years of most enjoyable antenna work

esa
Dinner on the occasion of the retirement of
Niels E. Jensen

4 generations: Niels, AR, Gerry & Cyril …..

+ some very supportive chiefs….

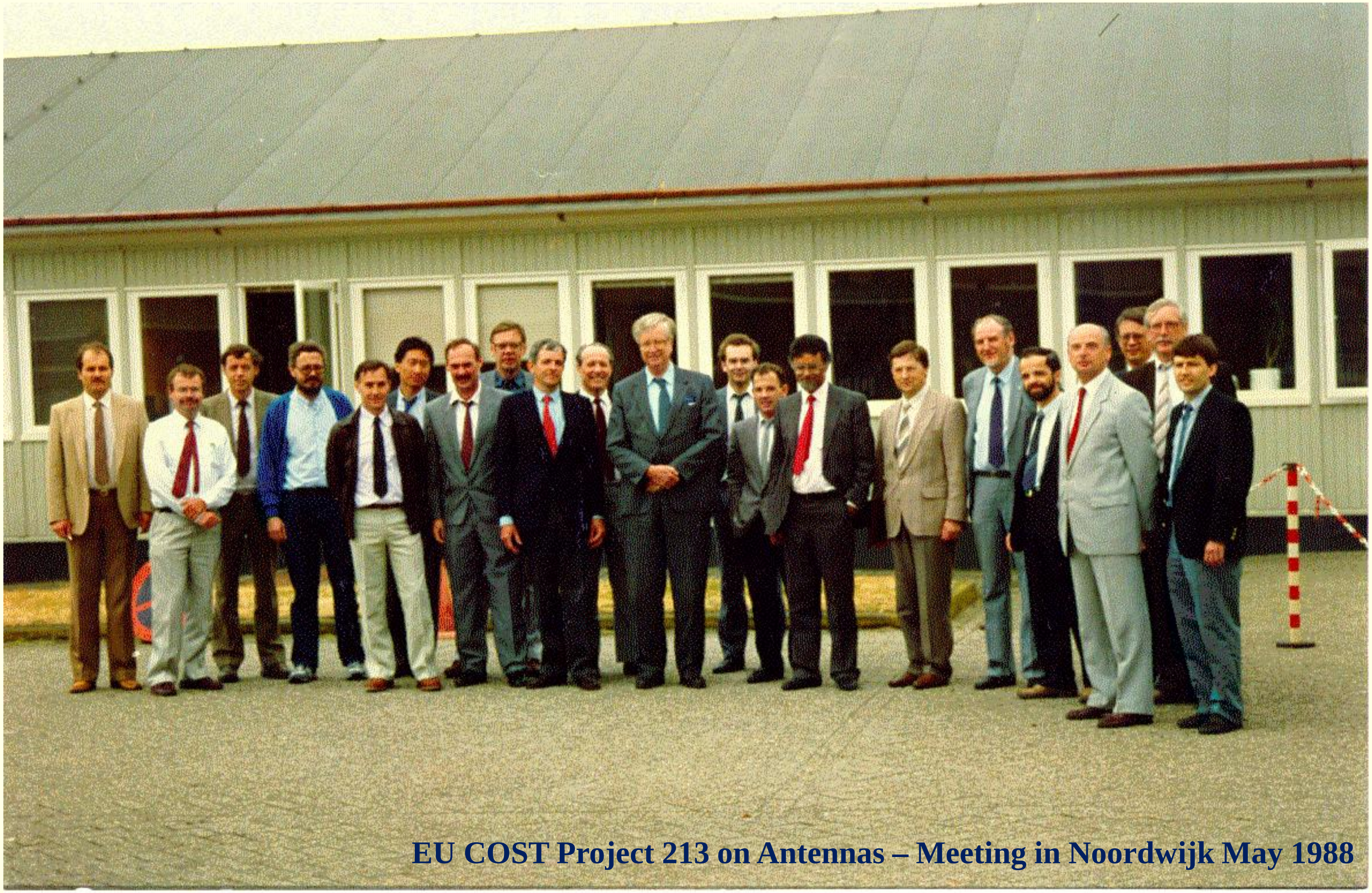
Thanks to a great Electromagnetics Division……

Courtesy BAR

Here some 23 Years ago (January 1991) …

© 2014 CMAR

Thanks to old Friends from Europe…..



EU COST Project 213 on Antennas – Meeting in Noordwijk May 1988

Thanks to many friends from overseas….

Davos 10 April 2000

And Good luck to Bertram Arbesser Rastburg and Cyril Mangenot !

Part II

Promising Space Antenna Concepts and Technologies

Cyril Mangenot

Head of Electromagnetics and Space Environment Division
European Space Agency

Presentation overview

Antennas are required for all Space missions (Earth Observation, Telecommunication, Navigation, Science, TT&C, human spaceflights and user terminals)

Optimization of antenna performances is requested for link budget and to increase overall system capacity

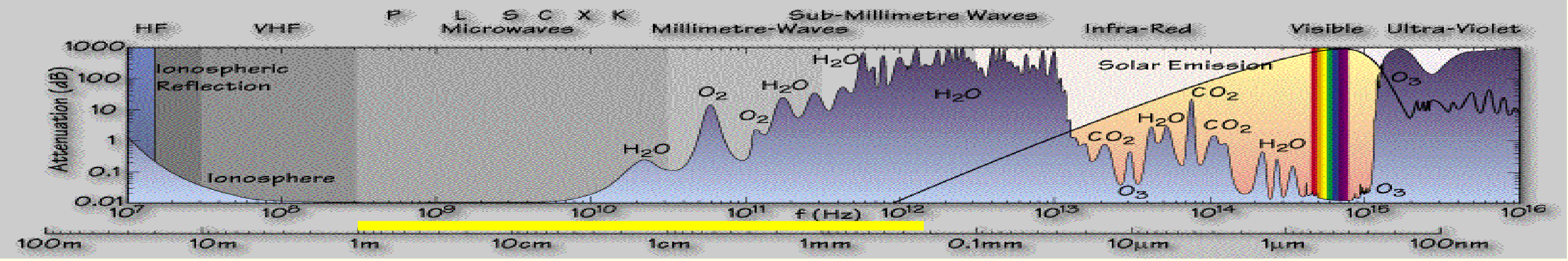
Antenna sub-systems are characterized by strong links with overall system design and spacecraft/mission optimization.

- ➔ *Mandatory to develop and maintain in parallel several antenna technologies, concepts and architectures for the different frequencies, bandwidths and radiating aperture diameters.*
- ➔ *Complex process involving several skills closely coordinated is required to ensure a competitive compromise between radio-electrical, mechanical and thermal performances.*

Presentation overview

Technologies and test techniques shall evolve to answer new Space mission needs over a larger frequency range: from VHF-band to sub-mm waves

1 mm
Rectangular Waveguide Profile
2.5 THz Corrugated Feedhorn Mandrel



How to classify future needs and promising concepts for space antennas?

by products?

- Natural choice but product definition and challenges differ significantly with the antenna architecture,

by applications?

- Well in line with the actual situation where the antenna design is optimized for a given mission,

by frequency range?

- Quite attractive as the size and technologies differ significantly over the space frequency spectrum,

Finally, considering on one side the requirements from projects and on the other side the R&D push for technologies/techniques with high potential, key space antenna challenges are proposed for the future R&D effort .

Identified key space antenna challenges

- **Develop large antenna apertures**
- **Increase telecommunication satellite throughput**
- Enable multiband and multipurpose antennas sharing the same aperture
- **Increase the competitiveness of well established antenna products**
- Promote technology push for enabling new missions
- **Enable single beam in flight coverage/polarization reconfiguration**
- Enable affordable Active antennas
- **Develop antennas for innovative Earth Observation and Science instruments**
- Evolve toward mass production of satellite and user terminal antennas
- **Develop new approaches for satellite/antenna modeling and testing**

(items in bold are addressed in next slides)

Develop large antenna apertures

Reflectors:

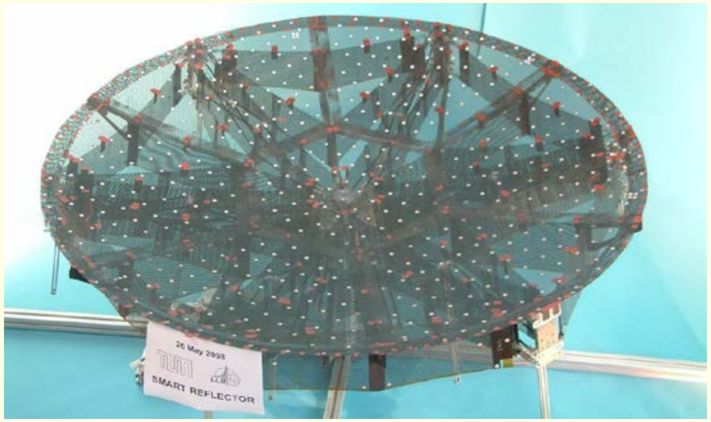
- Flexible shell-membranes enabling shaping
- Mesh compatible with Ka-band operation

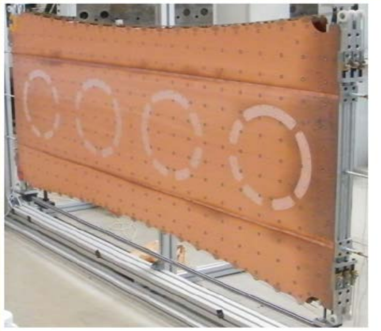
Direct Radiating Arrays:

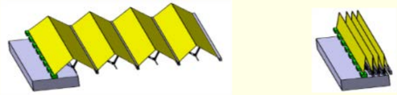
- 1D Folding of membranes (pantograph)

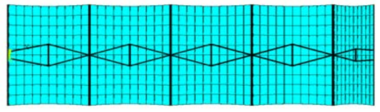
Reflectarrays:

- Multi facets aperture for increased bandwidth
- Low volume stowage for small satellites





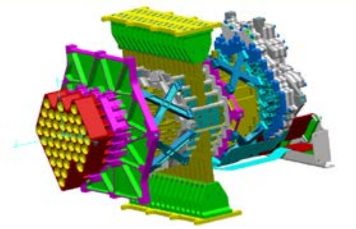


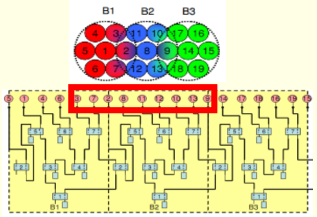


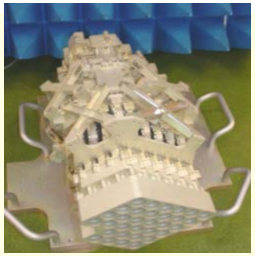
Increase telecommunication satellite throughput

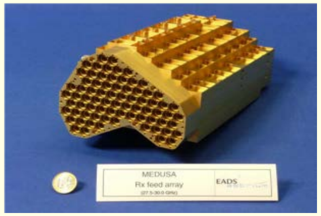
Multiple feed per beam concepts

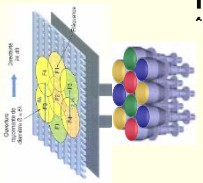
- Active Rx Feed Array Focal Reflector with low level BFN
- Passive Rx or Tx Focal array Reflector
- Overlapped feeds by Electromagnetic Band Gap radome with reflector
- Active discrete lens antenna

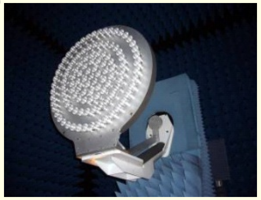


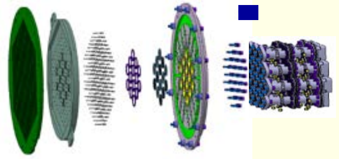


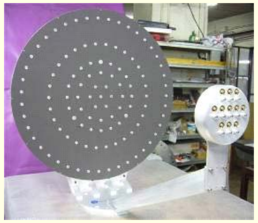












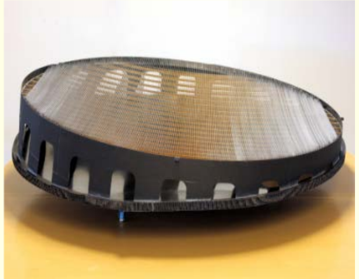
MFPB for primary or secondary missions?

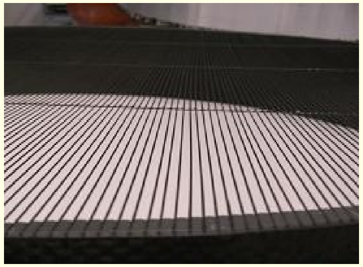
Increase the competitiveness of well established antenna products

Innovative antenna concepts:

- Develop new generation of full CFRP Dual Gridded reflector
- Develop compact global horn for telecom and medium Gain Antenna for EO /Scientific missions based on modulated metasurface

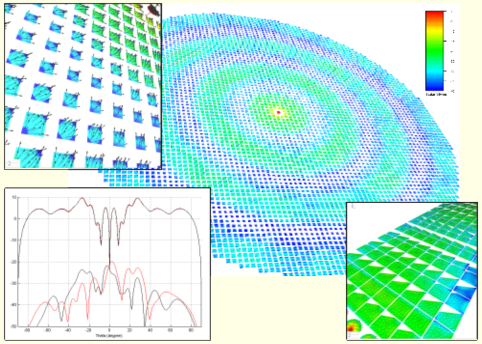
(University of Siena and partners)





RUAG
Aerospace Defence Technology

HPS
High Performance Space Structure Systems GmbH



Full-wave optimisation of holographic antennas

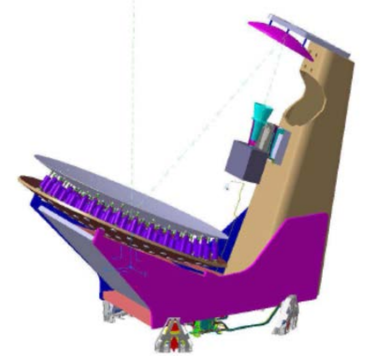
Enable single beam in flight coverage/polarization reconfiguration

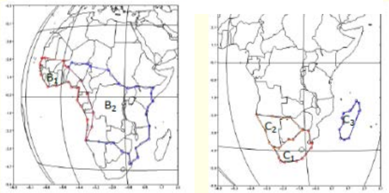
Mechanically reconfigurable antennas with pre-defined coverages using:

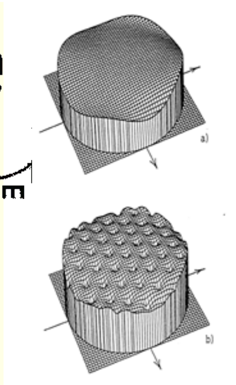
- conventional 2D-rotary actuators for the scanning ,
- mechanisms allowing to select an antenna aperture (sub reflector, array or reflectarray) generating a pre-defined coverage.

Mechanically in-flight reconfigurable antennas using:

- conventional 2D-rotary actuators for the scanning,
- several miniaturised linear actuators implemented behind the reflecting surface for the shaping.





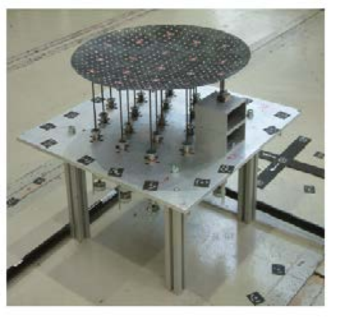


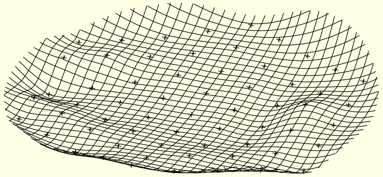
Circular aperture, D = 85 cm

Tricot mesh

50 control points with step motors

Fixed wooden frame





Diameter of model: 0.3 m

Piano wires, diameter: 0.3 mm

Distance between wires: 10 mm

Specific weight of wire grid: 92 g/m^2

Enable single beam in flight coverage/polarization reconfiguration

Reflectarray:

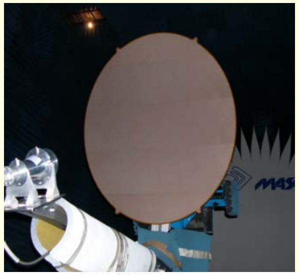
- Planar aperture with printed elements providing phase-shifts in reflection.
- Can generate two independent beams (one per polarisation).

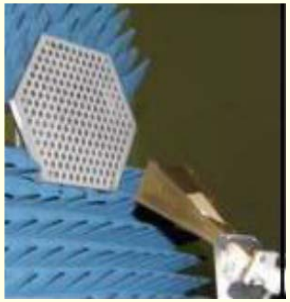
Passive reflectarrays

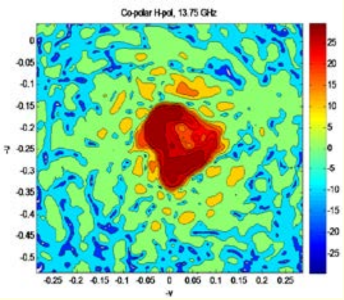
- Predefined coverage
- Selection of a coverage just before launch
- Selection of predefined coverage during life-time

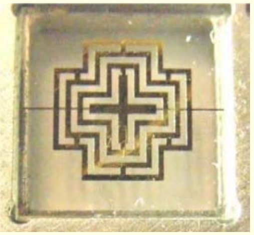
Active reflectarrays

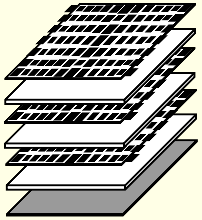
- In-flight reconfigurability by changing the phase reflection characteristics of the radiators thanks to active devices.
- Still major issues w.r.t. the space environmental constraints.











Develop antennas for innovative Earth Observation and Science instruments

Very large P and L-band radar:

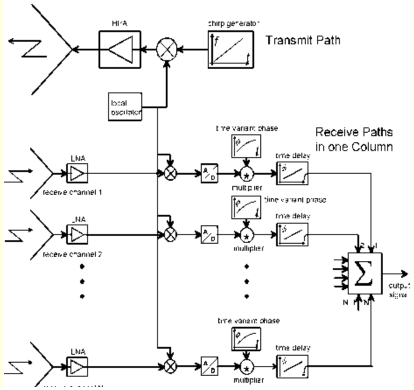
- Reflectors or planar arrays accommodation on small size platforms is critical. Less heritage on large reflector for LEO.

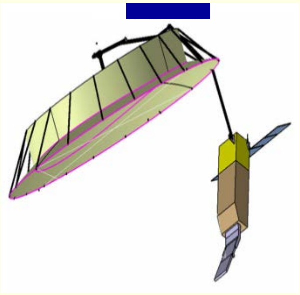
Reflector based SAR:

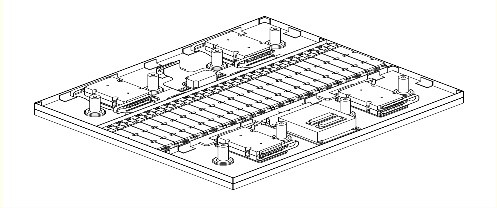
- Compatible with high resolution multi swath SAR. Spot light and scansar modes. Beam steering combined with spacecraft agility. High-power, low-loss feeds array are required with switched or orthogonal feed-network. Compatible with missions asking for multifrequency.

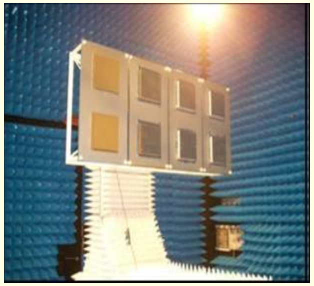
Digital SAR front-end :

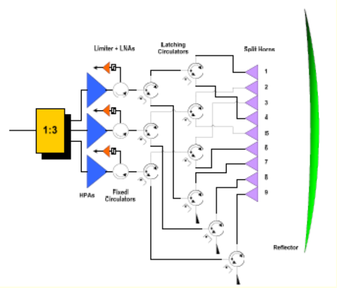
- Easy correction of discrepancies
- True Time delay, new SAR modes (MTI)
- Generic back-end

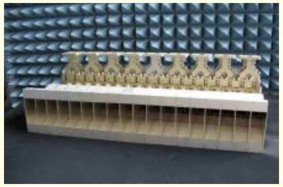

HPA
chirp generator
Transmit Path
local oscillator
time variant phase
Receive Paths in one Column
LNA
receive channel 1
time delay
multiplier
time variant phase
LNA
receive channel 2
time delay
multiplier
output signal
time variant phase
LNA
time delay
multiplier








Limiter + LNAs
Latching Circulators
Split Horns
1:3
1
2
3
4
5
6
7
8
9
HPAs
Fixed Circulators
Reflector

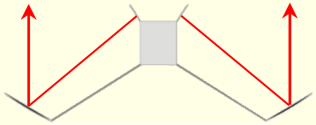


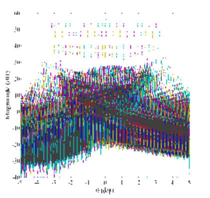
Develop antennas for innovative Earth Observation and Science instruments

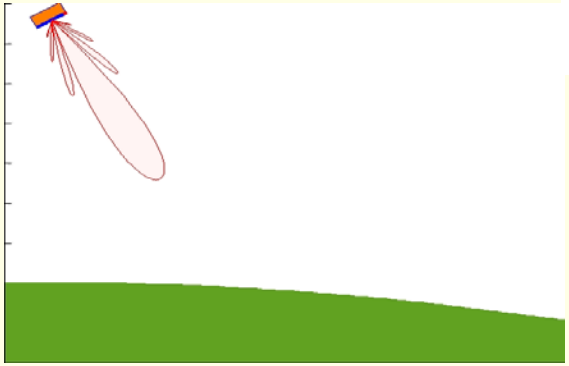
SAR Antenna Alternative Architectures:

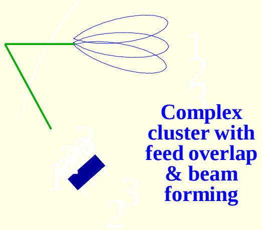
- Combined SAR/ Interferometric Radar Altimeter (CryoSat)
- High Resolution Ka-band SAR interferometry with only one satellite. Access to wider bandwidth . Need for 6 meter booms.
- Bi-static radar based on a separated passive low gain high power transmit antenna and active high gain receive scanning antenna using a digital beam-forming network.
- Passive Multiple beam instruments using GNSS signal reflection.

Saab Ericsson Space



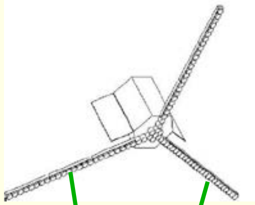





Complex cluster with feed overlap & beam forming

Operational mode	NESZ	Swath width	Resolution. (rg x az)
Sentinel 1 Sripmap mode	-22dB	80km	5m x 5m
Sentinel 1 EW mode	-22dB	400km	20m x 40m
HRWS	-22dB	400km	5m x 5m

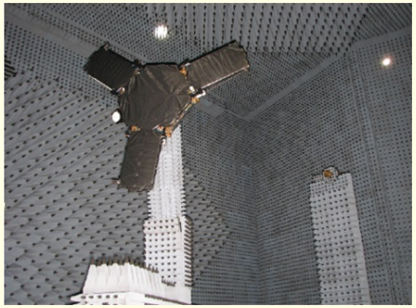
Develop antennas for innovative Earth Observation and Science instruments

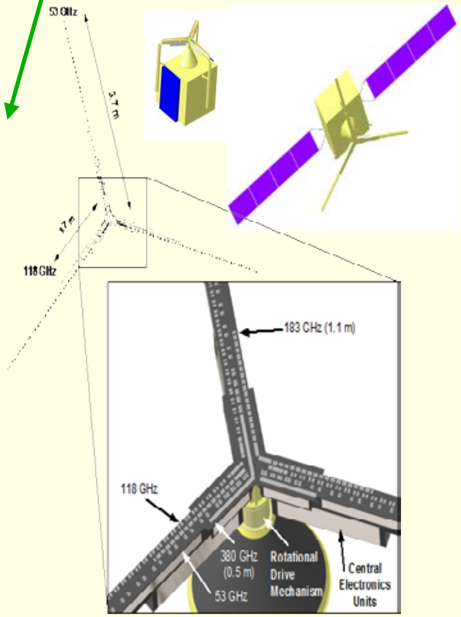


Interferometric/synthetic instruments antenna concepts:

- High-resolution with limited overall volume and mass. Large number of interferometric baseline allows some natural redundancy, observation over a large FOV, sparse arrays is of interest. Multifrequency can be implemented.

- SMOS Synthetic aperture radiometers now operational (LEO). L-band.

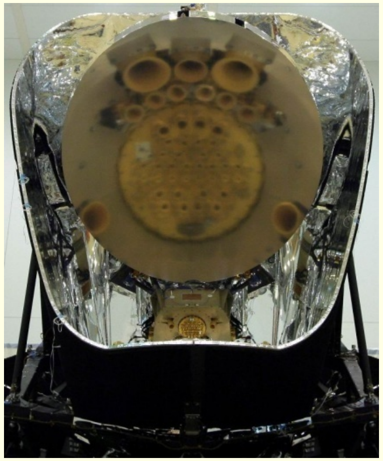


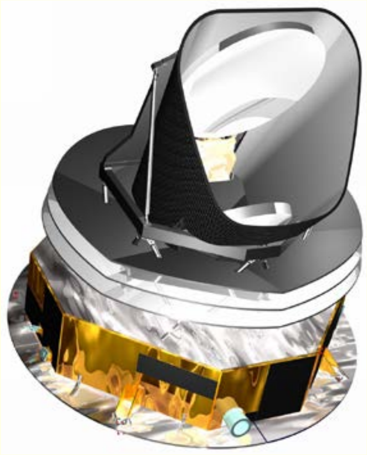

53 GHz
3.7 m
1.7 m
118 GHz
183 GHz (1.1 m)
118 GHz
380 GHz (0.5 m)
53 GHz
Rotational Drive Mechanism
Central Electronics Units

- GEO-SOUNDER potential candidate (GEO). Observation of rapidly evolving meteorological phenomena such as convective systems, precipitation and cloud patterns. Allows nowcasting. Proposed frequencies range from 54 to 875 GHz.

Develop antennas for innovative Earth Observation and Science instruments

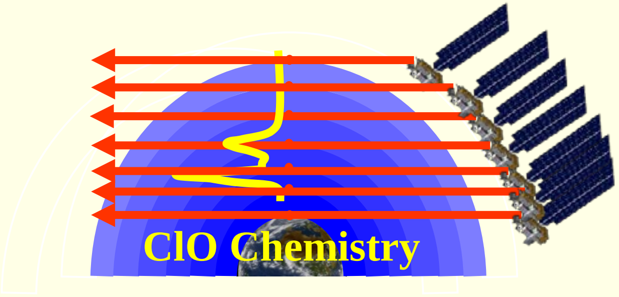
Polarimetric concepts for sub-millimetre wave instruments:





- **Polarisation properties of EM radiation: follow-on mission to Planck would require measurement of the polarisation properties of CMB radiation. Need for improvements in polarimetric antenna architectures and receivers. Astrophysics space mission B-POL asks it.**

- **Imaging arrays: for space astronomy and for atmospheric research. In astronomy, need to “map” the sky. Large size of the focal array and very high integration of the detectors/readout systems.**



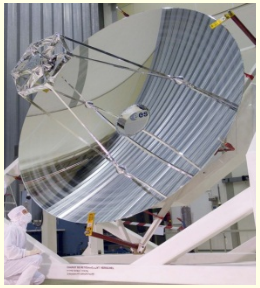
- **Atmospheric Chemistry Spaceborne millimeter wave limbsounder instruments: provides data products for climatology and for operational meteorology for Earth and planetary missions.**

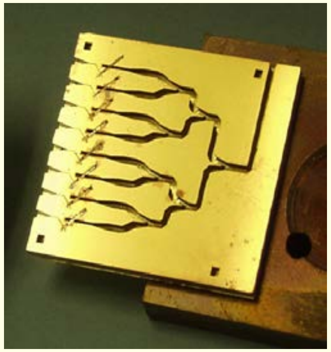
Use of several spectroscopic regions, from 290 GHz up to 3.5 THz. Access to atmospheric chemicals, from greenhouse gases (mainly in mm-wave) and ozone depleting agents (mainly at submm-wave) to the hydroxyl free radical (terahertz range).

Develop antennas for innovative Earth Observation and Science instruments

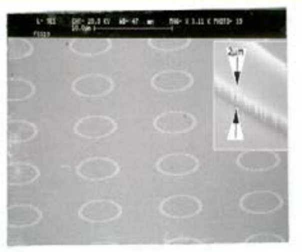
Technologies:

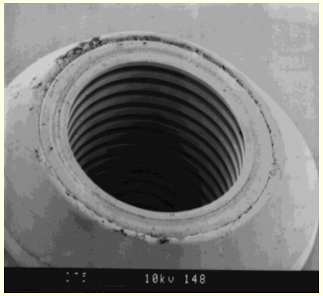
- **High Accuracy/Stability Reflectors and Structures:** Imposed by high resolution, pointing accuracy, wide scanning range. Differential insertion phase stability for interferometers.
- **Improved multi-frequency Quasi-Optical feed boxes:** Move up in frequency and increase of nbr of channels for EO. QO boxes to be compatible with demux, scanning/beam-rerouting capabilities, calibration. Very high sensitivity.
- **Novel micro machining manufacturing techniques:** excellent electrical performance, low weight and repeatable fabrication routes with suitable structural properties. Extremely compact achievable size (imaging arrays). Application to FSS and submmwave feed horns with micron accuracy.





Twin 8-element micromachined array (Courtesy of Rutherford Appelton Laboratory))





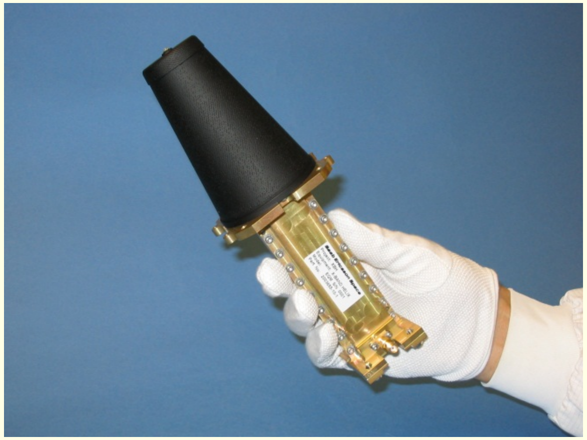
Quasi-optical multi-layer free standing micromachined array of slot elements Courtesy of Queens University of Belfast

Develop antennas for innovative Earth Observation and Science instruments :

Need for a new generation of data transmission Antennas

Dual polarisation steerable pencil beam X-band antenna

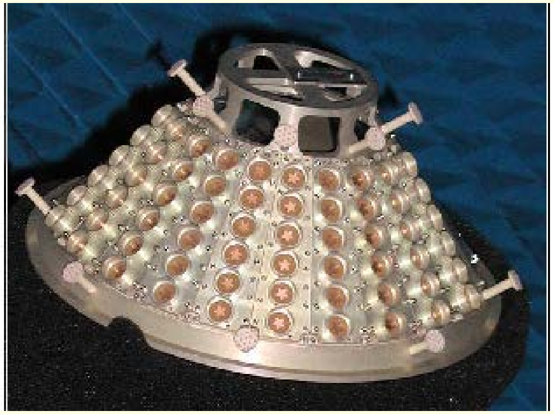
- To mitigate interferences due to the use of using isoflux antennas sharing the frequency allocation.
- To increase data rate while reusing existing X-band on ground/space equipments



Quadrifilar X-band helix antenna with isoflux pattern.
(Courtesy of RUAG Space Sweden)

Ka-band mechanically and electronically steerable antennas

- For EO links: frequency band 25.5-27 GHz. High down link data rates (up to 1.5 Gb/s).
- For Deep Space exploration: 31.8-32.3 GHz and 37-38 GHz. Typical data rate values are 10 Mb/s but strong environmental constraints. Avoid perturbations due to antenna moving parts.



Conformal array
(Courtesy of Thales Alenia Space France)

Domains requiring further developments (modeling/testing)

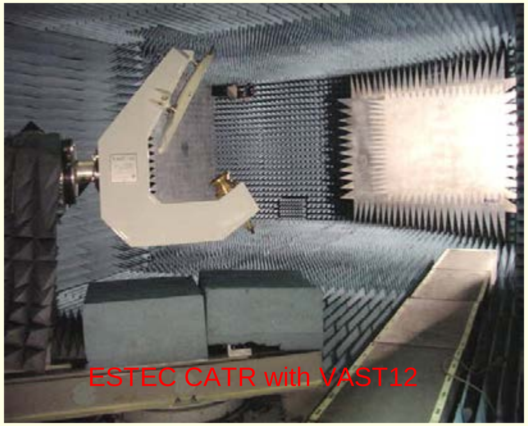
Develop new approaches for satellite/antenna modeling and testing

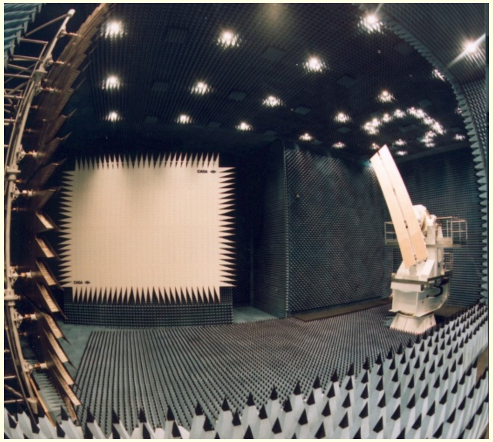
- **Innovative approaches for efficient Antenna/Payload/AIT-AIV RF characterisation, direct measurement of payload performances for multibeam antennas, High power testing, signal processing antenna testing, Near-Field Antenna PIM Products Testing with processing to localize the PIM sources,**
- **Put in place Low Frequency Very Large Antenna Performance verification Methodologies and Facilities,**
- **Develop accurate characterisation of radiated phase for interferometric instruments and Navigation antennas,**
- **Develop test techniques for sub-mm wave antenna measurements, such as Phaseless Near Field and develop sub-mm facilities,**
- **Characterization of the RF properties of material and processes involved in antenna design,**
- **Improve measurement / error correction techniques for very low sidelobe antennas,**

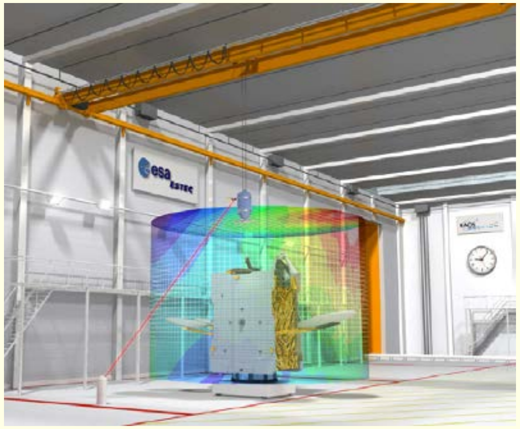
Domains requiring further developments (modeling/testing)

Develop new approaches for satellite/antenna modeling and testing

- Investigate combined measurement-simulation approaches to reduce testing time,
- Develop Diagnostic Tests Techniques for Trouble Shooting of Antennas during Satellite AIV,
- Make available New VAlidation STandard (VAST) antenna to assess the accuracy of antenna ranges at 20/30/38/48 GHz.





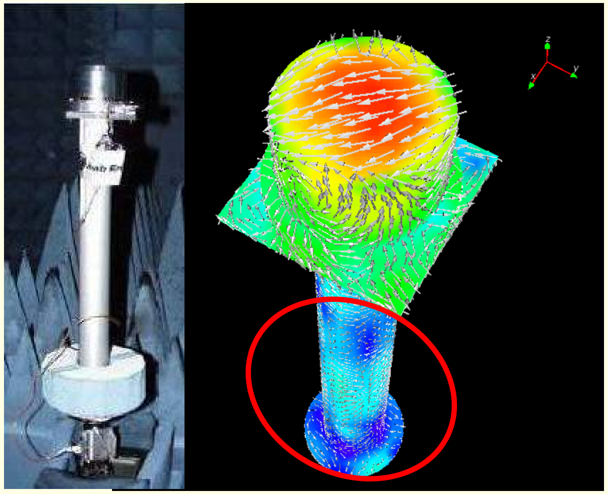


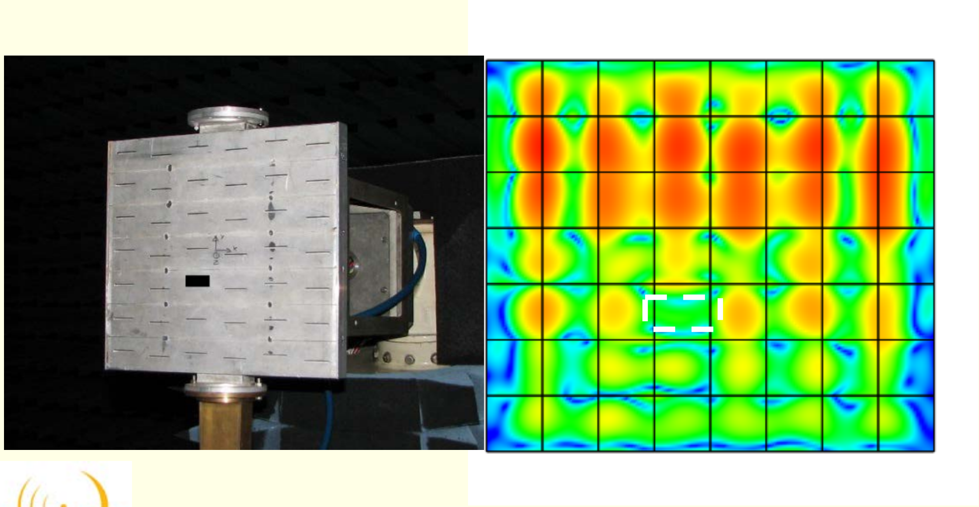
Domains requiring further developments (modeling/testing)

Combination of advanced RF modeling tools and testing

Exploiting accurate test methods and powerful modeling tools (DIATOOL, INSIGHT) in tight combination one can:

- provide more details about performance without significantly affecting test methods and facilities
- Use all available information to understand the cause of problems and correct them





Data processing and data exchange

Today, more and more synergies between the modelling and the testing domains.

Strong interest to ease the way to exchange simulated and measured data without loss of information.

Need to make further progress on tools interoperability as captured by the Electromagnetic Data Exchange language.

More information at http://www.antennasvce.org/Public/EDX

Thanks to ESA colleagues with a special mention to Julian Santiago-Prowald, Peter de Maagt, Giovanni Toso, Luca Salghetti Drioli…

Thanks to partners involved in the presented developments.